Connecting to Your World

Nearly all of the adult population suffers from acid indigestion at some time. Although hydrochloric acid is always present in the stomach, an excess can cause heartburn and a feeling of nausea. A common way to relieve the pain of acid indigestion is to take antacids to neutralize the stomach acid. The active ingredient in many antacids is sodium hydrogen carbonate, aluminum hydroxide, or magnesium hydroxide. In this section, you will learn what a neutralization reaction is.

Guide for Reading

Key Concepts

- What are the products of the reaction of an acid with a base?
- What is the endpoint of a titration?

Vocabulary

neutralization reactions
equivalence point
titration
standard solution
end point

Reading Strategy

Identifying a Sequence A sequence is the order in which a series of events occurs. As you read about acid-base titrations, list the steps that should be used in carrying out a precise titration. Include the reactants and how they are measured, the indicator, and what to look for as the titration nears its end point.

Acid-Base Reactions

If you mix a solution of a strong acid containing hydronium (hydrogen) ions with a solution of a strong base that has an equal number of hydroxide ions, a neutral solution results. The final solution has properties that are characteristic of neither an acidic nor a basic solution. Consider these examples:

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

$$H_2SO_4(aq) + 2KOH(aq) \longrightarrow K_2SO_4(aq) + 2H_2O(l)$$

In each example, a strong acid reacts with a strong base. If solutions of these substances are mixed in the mole ratios specified by the balanced equation, neutral solutions will result. Similar reactions of weak acids and/or weak bases do not usually produce neutral solutions. In general, however, reactions in which an acid and a base react in an aqueous solution to produce a salt and water are called **neutralization reactions.** The formation of water in a neutralization reaction is shown in Figure 19.20.

Neutralization reactions are one way to prepare pure samples of salts. You could prepare potassium chloride, for example, by mixing equal molar quantities of hydrochloric acid and potassium hydroxide. An aqueous solution of potassium chloride would result. You could heat the solution to evaporate the water, leaving the salt potassium chloride. Table 19.9 lists some common salts and their applications.

In general, the reaction of an acid with a base produces water and one of a class of compounds called salts. When you hear the word *salt,* you may think of the substance that flavors your French fries or scrambled eggs. Table salt (sodium chloride) is one example of a salt, but there are many more. Salts are compounds consisting of an anion from an acid and a cation from a base.

Figure 19.19 For fish and other aquatic animals to survive, the water in which they live must be maintained at the proper pH.

Name	Formula	Applications
Ammonium sulfate	$(NH_4)_2SO_4$	Fertilizer
Barium sulfate	$BaSO_4$	Gastrointestinal studies; white pigment
Calcium chloride	$CaCl_2$	De-icing roadways and sidewalks
Potassium chloride	KCl	Sodium-free salt substitute
Silver bromide	AgBr	Photographic emulsions
Sodium hydrogen carbonate (baking soda)	$NaHCO_3$	Antacid
Sodium carbonate decahydrate (washing soda)	$Na_2CO_3 \cdot 10H_2O$	Glass manufacture; water softener
Sodium chloride (table salt)	NaCl	Body electrolyte; chlorine manufacture

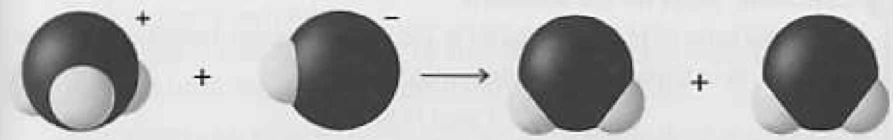

Figure 19.20 In a neutralization reaction, hydronium ions (H_3O^+) combine with hydroxide ions (OH^-) to form neutral water.

The properties of acids, bases, and salts help explain many diverse phenomena. The usefulness of antacids, for example, depends on the process of acid-base neutralization. Farmers use a similar process to control the pH of soil.

Titration

Acids and bases sometimes, but not always, react in a 1:1 mole ratio.

$$\underset{1\ \text{mol}}{HCl(aq)} + \underset{1\ \text{mol}}{NaOH(aq)} \longrightarrow \underset{1\ \text{mol}}{NaCl(aq)} + \underset{1\ \text{mol}}{H_2O(l)}$$

When sulfuric acid reacts with sodium hydroxide, however, the ratio is 1:2. Two moles of the base sodium hydroxide are required to neutralize one mole of H_2SO_4.

$$\underset{1\ \text{mol}}{H_2SO_4(aq)} + \underset{2\ \text{mol}}{2NaOH(aq)} \longrightarrow \underset{1\ \text{mol}}{Na_2SO_4(aq)} + \underset{2\ \text{mol}}{2H_2O(l)}$$

Similarly, hydrochloric acid and calcium hydroxide react in a 2:1 ratio.

$$\underset{2\ \text{mol}}{2HCl(aq)} + \underset{1\ \text{mol}}{Ca(OH)_2(aq)} \longrightarrow \underset{1\ \text{mol}}{CaCl_2(aq)} + \underset{2\ \text{mol}}{2H_2O(l)}$$

You will notice in the preceding examples that the number of moles of hydrogen ions provided by the acid are equivalent to the number of hydroxide ions provided by the base. When an acid and base are mixed, the **equivalence point** is when the number of moles of hydrogen ions equals the number of moles of hydroxide ions.

Checkpoint ***What is the equivalence point of a reaction between an acid and a base?***

How many moles of sulfuric acid are required to neutralize 0.50 mol of sodium hydroxide?

1 Analyze ***List the knowns and the unknown.***

Knowns

- mol NaOH = 0.50 mol
- $H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$
- $\frac{\text{mol } H_2SO_4}{\text{mol NaOH}} = \frac{1}{2}$

Unknown

- moles H_2SO_4 = ? mol

2 Calculate ***Solve for the unknown.***

The mole ratio of H_2SO_4 to NaOH is 1:2. The necessary number of moles of H_2SO_4 is calculated using this ratio.

$$0.50 \cancel{\text{mol NaOH}} \times \frac{1 \text{ mol } H_2SO_4}{2 \cancel{\text{mol NaOH}}} = 0.25 \text{ mol } H_2SO_4$$

3 Evaluate ***Does the result make sense?***

Because the mole ratio of H_2SO_4 to NaOH is 1:2, the expected number of moles of H_2SO_4 should be half the given number of moles of NaOH. The answer should have two significant figures.

Math Handbook

For help with dimensional analysis, go to page R66.

Practice Problems

30. How many moles of potassium hydroxide are needed to completely neutralize 1.56 mol of phosphoric acid?

31. How many moles of sodium hydroxide are required to neutralize 0.20 mol of nitric acid?

Interactive Textbook

Problem-Solving 19.30 Solve Problem 30 with the help of an interactive guided tutorial.

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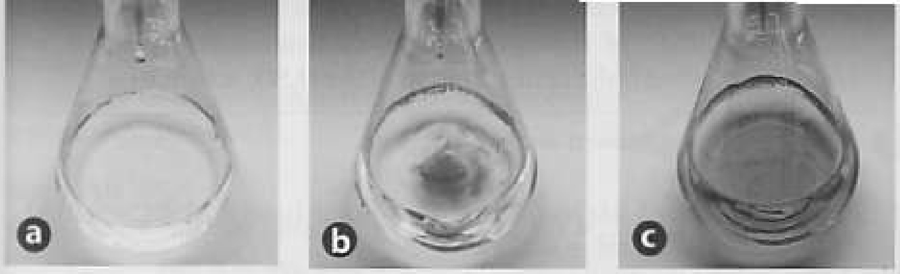
You can determine the concentration of acid (or base) in a solution by performing a neutralization reaction. You must use an appropriate acid-base indicator to show when neutralization has occurred. As you can see in Figure 19.21, the juice of the red cabbage is an acid-base indicator. In the laboratory, phenolphthalein is often the preferred indicator for acid-base neutralization reactions. Solutions that contain phenolphthalein turn from colorless to deep pink as the pH of the solution changes from acidic to basic. In slightly basic solutions, the indicator is very faintly pink.

Figure 19.21 Red cabbage juice is used as an acid-base indicator. As the solution changes from highly acidic to basic, the color changes from red to violet to green to yellow. **Predicting** ***Would the yellow solution have a high or low pH?***



acid (plus a few drops of phenolphthalein indicator) in a flask is placed beneath a buret filled with a base of known concentration. **b** Base is slowly added from the buret to the acid while the flask is gently swirled. **c** A change in the color of the indicator signals that neutralization has occurred.

The steps in a neutralization reaction are as follows.

1. A measured volume of an acid solution of unknown concentration is added to a flask.
2. Several drops of the indicator are added to the solution while the flask is gently swirled.
3. Measured volumes of a base of known concentration are mixed into the acid until the indicator just barely changes color.

The process of adding a known amount of solution of known concentration to determine the concentration of another solution is called **titration.** The solution of known concentration is called the **standard solution.** Use a buret to add the standard solution. A titration is continued until the indicator shows that neutralization has just occurred. The point at which the indicator changes color is the **end point** of the titration. The titration of an acid of unknown concentration with a standard base is shown in Figure 19.22. You can use a similar procedure to find the concentration of a base using a standard acid.

Interactive Textbook

Simulation 26 Simulate the titration of several acids and bases and observe patterns in the pH at equivalence.

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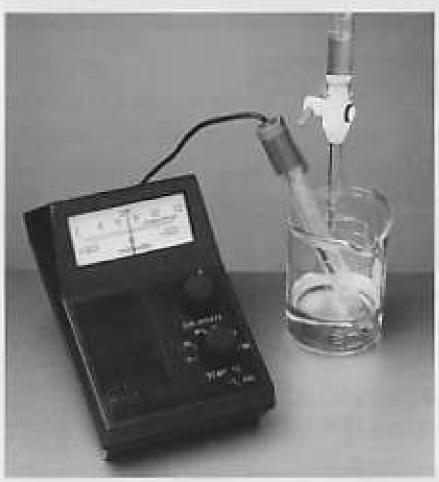
Figure 19.23 shows how the pH of a solution changes during the titration of a strong acid (HCl) with a strong base (NaOH). The pH of the initial acid solution is low. As the base is added, the pH increases because some of the acid is neutralized. As the titration approaches the point of neutralization, at a pH of 7, the pH increases dramatically as hydrogen ions are used up. Once past the point of neutralization, additional base produces a further increase of pH. **The point of neutralization is the end point of the titration.** At this point, the contents of the beaker consist of only H_2O and NaCl, which is the salt derived from the strong acid HCl and the strong base NaOH, plus a trace of indicator.



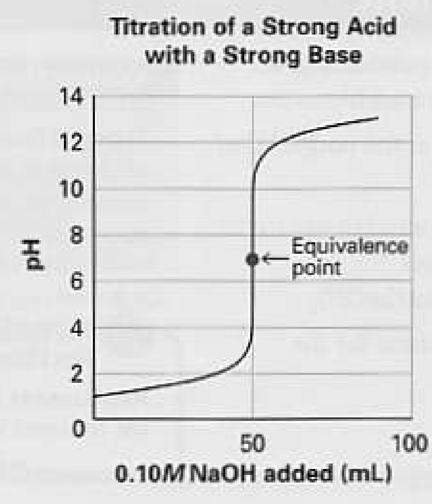


Figure 19.23 In this titration of a strong acid with a strong base, 0.10*M* NaOH is slowly added from a buret to 50.0 mL of 0.10*M* HCl in the beaker. The equivalence point, the midpoint on the vertical portion of the pH titration curve, occurs at 50.0 mL of NaOH added. **Interpreting Diagrams** ***What is true concerning [H^+] and [OH^-] at the equivalence point?***

A 25-mL solution of H_2SO_4 is completely neutralized by 18 mL of 1.0M NaOH. What is the concentration of the H_2SO_4 solution?

1 Analyze ***List the knowns and the unknown.***

Knowns

- molarity base = 1.0M NaOH
- volume base = 18 mL = 0.018 L
- volume acid = 25 mL = 0.025 L
- $H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$

Unknown

- molarity acid = ?M H_2SO_4

Use the molarity to convert the volume of base to moles of base. Use the mole ratio to find the number of moles of H_2SO_4. Calculate the molarity by dividing the number of moles of H_2SO_4 by the number of liters of H_2SO_4.

The conversion steps are as follows:

$$\text{L NaOH} \longrightarrow \text{mol NaOH} \longrightarrow \text{mol } H_2SO_4 \longrightarrow M\ H_2SO_4$$

2 Calculate ***Solve for the unknown.***

$$0.018\ \cancel{\text{L NaOH}} \times \frac{1.0\ \cancel{\text{mol NaOH}}}{1\ \cancel{\text{L NaOH}}} \times \frac{1\ \text{mol } H_2SO_4}{2\ \cancel{\text{mol NaOH}}} = 0.0090\ \text{mol } H_2SO_4$$

$$\text{molarity} = \frac{\text{moles}}{\text{liters}} = \frac{0.0090\ \text{mol}}{0.025\ \text{L}} = 0.36\ M$$

The $[H_2SO_4]$ is 0.36M.

3 Evaluate ***Does the result make sense?***

Because the volume of acid was greater than the volume of base, the concentration is less than 1.0M. The answer has two significant figures.

Math Handbook

For help with dimensional analysis, go to page R66.

Practice Problems

32. How many milliliters of 0.45M HCl will neutralize 25.0 mL of 1.00M KOH?

33. What is the molarity of H_3PO_4 if 15.0 mL is completely neutralized by 38.5 mL of 0.150M NaOH?

Interactive Textbook

Problem-Solving 19.33 Solve Problem 33 with the help of an interactive guided tutorial.

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19.4 Section Assessment

34. **Key Concept** What are the products of a reaction between an acid and a base?

35. **Key Concept** What occurs at the endpoint of a titration?

36. How many moles of HCl are required to neutralize aqueous solutions of these bases?
    a. 2 mol NH_3
    b. 0.1 mol $Ca(OH)_2$

37. Write complete balanced equations for the following acid-base reactions?
    a. $H_2SO_4(aq) + KOH(aq) \longrightarrow$
    b. $H_3PO_4(aq) + Ca(OH)_2(aq) \longrightarrow$
    c. $HNO_3(aq) + Mg(OH)_2(aq) \longrightarrow$

Connecting Concepts

Types of Reactions Reread the information on types of chemical reactions in Section 11.2. Which type of reaction are all acid-base neutralizations? Explain your answer.

Interactive Textbook

Assessment 19.4 Test yourself on the concepts in Section 19.4.

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